Comfort Evaluation Method of Commercial Pilot Posture

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Abstract. Comfortable pilot posture is the important guideline for flight deck design and evaluation. The present evaluation methods used to evaluate the whole posture comfort only consider the manikin geometry performance such as joint angles' but the biomechanical performance. A joint load model was built considering the mechanical performance based on the comfort analysis of the usable joints torque. Through the experiment on the flight deck simulator the data of joint torque and angles were collected. The comfort analysis of pilot posture was executed both by load model and the general analysis by joint angles' fuzzy evaluation. The results show that the two methods have the identical evaluation conclusion, but the load model is more objective and avoid the subjective of fuzzy evaluation. The load model based on the usable torque of joints can discover the design problem of the whole layout of flight deck and furthermore, the model can be used to solve the problems of manipulation efficiency of local operation such as press, pull/push and so on which is always the important aspects of ergonomic design.

1 Introduction

Comfortable pilot posture is basis for flight deck design and evaluation. With the development of computer aided design there are many industry softwares such as CATIA/DELMIA [1, 2], RAMSIS [3], JACK [4], which is used for flight deck design and ergonomics evaluation. The current models can't build postures as exact as real pilots [5]. This induces design error and evaluation error. How to analysis the comfort of postures is important. The anthropometry data joint angles are always used for pilot comfort analysis [2, 6–8]. The essence of comfort is capability of joint load enduring. But there are some researchers argued that the joint load and joint angles have the same evaluation effect [9, 10]. But joint load is not only related with joint angles but also joint length, muscle density [11]. The joint angles evaluation has been proved to be not consistent with the actual evaluation by real pilot. Joint load model is a function of joint load and has been validated. The consistency effect of joint angle s and joint load for pilot comfort has been discussed. This research is important for flight deck ergonomic design and evaluation in accuracy and engineer's workload.

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2 Joint Load Model

For static postures, different postures have different muscle contraction forces exhibited by different joint loads. Subjective comfort sensitivity can be represented by usable joint load which is also the control capability for joints. The maximum joint moment people can endure is confirmed, the more the load is the less the usable moment is and then the ability of self-adjustment reduces so is the comfort sensitivity.

For static posture, the main joint load of pilot is the load produces by muscle gravity. The model is built on the hypothesis that the ratio between usable joint load and maximum joint load can be used to represent comfort. Because the greater ratio suggests that the people have bigger ability to control the joints and the control ability means comfort. The static posture comfort is defined as C, and C is the function of usable moment F_i of different joints, which is the difference between maximum load and actual load of pilot.

$$C = \sum_{i}^{n} \left(A_i * \left(F_{imax} - F_{ir}\right)/F_{imax}\right) \tag{1}$$

Where, i means joint i, A_i means the weight of joint i. The value of A_i is defined by the scale of joint angle. The larger the scale is the less sensitive the joint of comfort, vice verse. If the two joints i and j have the scale a, b and then the weight is $b/(a + b)$, $a/(a + b)$ respectively.

The load model is validated by the pilot static posture experiment.

3 Validated Experiment

3.1 Experiment Design

The experiment is executed in the flight deck simulator and during the experiment the subjective comfort must be guaranteed.

The flight deck has complicated capture environment, such as the electromagnetism, limited space room and illuminance and so on. The experiment also needs to guarantee the pilot's smooth operation. There are various capture equipments such as optical equipment, electromagnetism equipment and acoustical equipment. The optical equipment can't be used because of the illuminance limits, and the electromagnetism equipment also can't be used because of the electromagnetism limits, because of the obstacles the acoustical equipment also has limitations, and the inertial equipment used mostly at present would affect the pilot's operation. The fiber optic capture is finally chosen to capture the postures. This equipment's angle differentiate is 0.5°, and the position differentiate is 1 ~ 3 mm, which can satisfy the analysis demand.

There are five pilots and the data of the stick operation is captured and the motion should repeat ten times. Before the record, the pilot should adjust the seat to make himself in the most comfortable posture at the eye point (Fig. 1).

Fig. 1. Scene of static pilot posture experiment

3.2 Experiment Result

In the experiment, the diameter of the stick is about 30 cm, and the average chest breadth is about 30.6 cm, the difference is 6 mm. The posture can be simplified as paralleling to the body's sagittal plane. In this simplify the angle between forearm and upper arm is in the sagittal plane. The whole posture can be represented as flexion/extend angle of elbowα_1, flexion/extend angle of shoulderβ shown in Fig. 2.

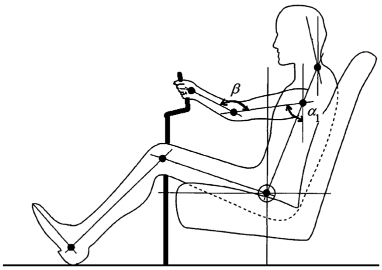

Fig. 2. The simplified posture representation

The experiment data has been calculated shown is Figs. 3 and 4 with different stature.

From Figs. 3 and 4, the joint angle and joint torque both increase with the stature. And the different joint angles have the same trend.

4 Validation

4.1 Calculation Process

1. The Weight Value A

From the research result of Tie [12], scale of α_1 is [11°, 39°], and the range is 28°, scale of β is [96°, 126°], and the range is 30°. According to the method mentioned above, the weight value is 0.52, 0.48 respectively.

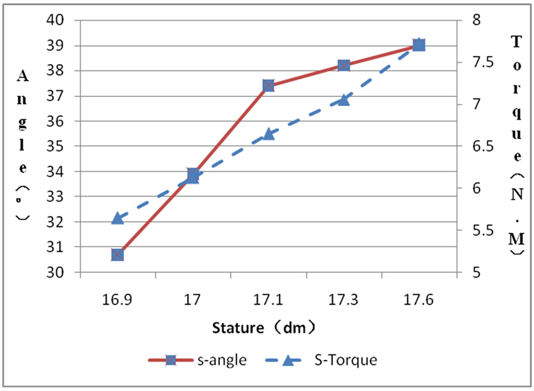

Fig. 3. Torque and flexion/extend angle of shoulder with different stature

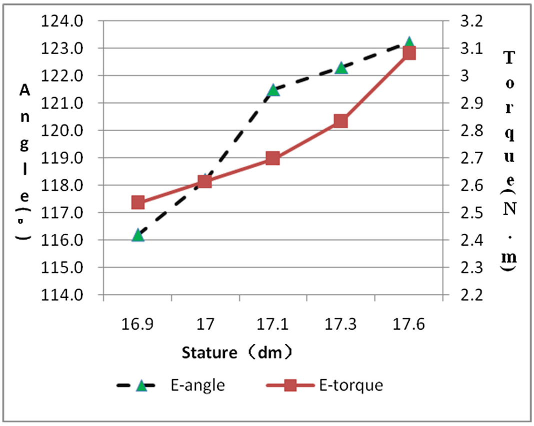

Fig. 4. Torque and flexion/extend angle of elbow with different stature

2. Maximum Torque

The maximum torque can be calculated through NASA strength model. The elbow angle should use the supplementary angle of the angle in the experiment. The final maximum torque is shown in Table 1, and the actual torque pilot stand in the posture can be gotten by the simulation of lifemod software shown in Table 1.

Table 1. Maximum torque of different joints' angles

Shoulder angles (°)	30.7	33.9	37.4	38.2	39
Max torque (N.m)	34.7	34.1	33.4	33.2	33.1
Actual torque (N.m)	5.6	6.1	6.6	7.1	7.7
Eblow angles (°)	63.8	61.8	58.5	57.7	56.8
Max torque (N.m)	15.9	16.4	17.2	17.4	17.6
Actual torque (N.m)	2.5	2.6	2.7	2.8	3.1

3. Comfort Value

The comfort value C of different is calculated by the comfort model and is shown in Figs. 5, 6 and 7.

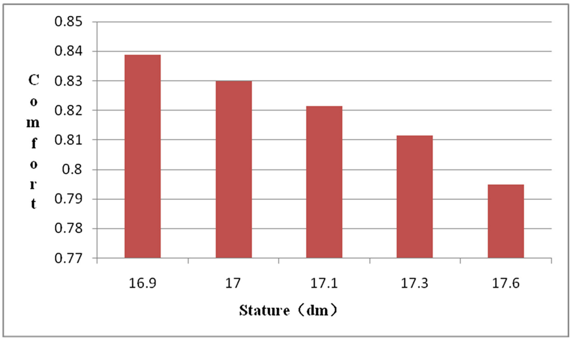

Fig. 5. Stature and comfort

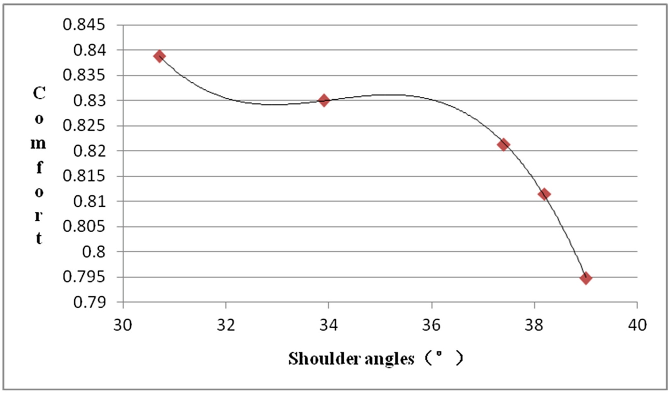

Fig. 6. Comfort and shoulder joints

The comfort of five pilots didn't change so much, and the value is all more than 0.5 which also suggests that the data of experiment is effective. From the result, the comfort decreases with the increasing of stature. There are two reasons which can interpret the phenomenon. First, the taller pilots means longer limbs, bigger muscle contraction force and then larger load needs to maintain the posture, the usable torque is less; and second reason is the flight deck doesn't have enough room and to complete the operation, the taller people has more limitations.

From Figs. 5 and 6, in the comfortable joint angle range, the comfort is just in the same level, but when out of the range,the comfort changes more, and the comfort value is more sensitive with joint angles.

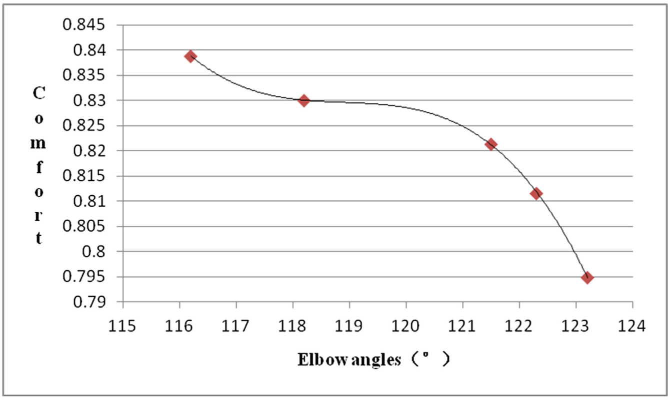

Fig. 7. Comfort and elbow joints

4.2 Validation

1. Validation of Consistency Affection of Comfort By Joint Angles And Joint Loads
From Figs. 8 and 9, the joint angles and joint torques have the same monotony trend with stature, which means the joint angles can be used to represent joint load's trend; from Figs. 3 and 4, the joint load increases with the joint angles which is another proof of the consistency.

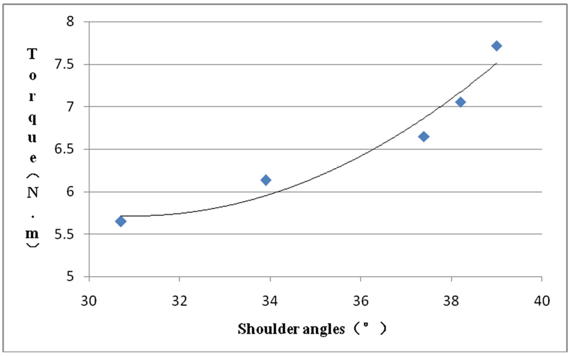

Fig. 8. Shoulder joint torque with different joint angles

The joint loads come from muscle contraction force mainly, and the value of the force is with the posture directly. This chain can explain why the two have almost the same evaluation method. But because of the differences of stature, density, weight and so on the two also have a bit difference.

2. Validation of Joint Load Model
The evaluation result by joint load model is all bigger than 0.8, which suggests that the posture is comfortable. The fuzzy evaluation method used joint angles to evaluate the same posture give the result is also "comfort", the two give the same evaluation.

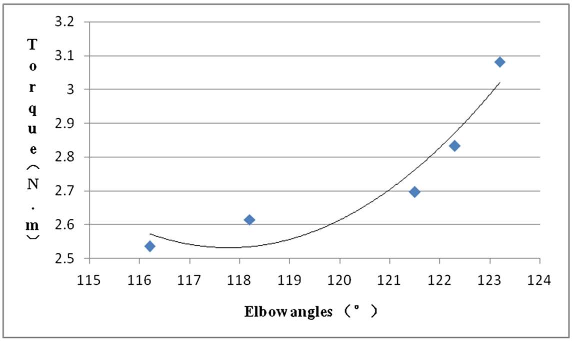

Fig. 9. Elbow joint torque with different joint angles

Because fuzzy method has been validated, the load model is also effective. But the quantitative value is more convenient and intuitionistic for engineer to use. It is most important that the load model is an objective method.

5 Conclusion

Whether the posture is comfort depends on the layout of flight deck, and the comfort posture is also the basis of flight deck design and evaluation. Joint load is the essence of pilot operation comfort. The comfort evaluation model built here is the function of joint torque. The larger the usable toque is the more comfort for pilot. The model can not only solve the problem of layout of flight deck, but also the efficient and comfort of various operations such as push/pull, dial and so on. Comfort and efficient is essential for ergonomics design.

Joint angle the anthropometry data represents the pilot posture, and joint load the essential biodynamic character data can reflect the joint inner mechanical nature. The consistence analysis between joint angle and load in comfort analysis based on the experimental data suggest that the two has almost the same effect on the posture comfort. But the comfort load model is the quantitative method for pilot posture comfort evaluation and through the evaluation process which joint is discomfort can be found easily and so to find the design limitation.

For the primary flight deck design evaluation, the joint angle evaluation method can give the result easily and conveniently, but when coming to the particular design the joint load model is recommended because of its precise and effective.

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